Evaluation of Sliding Identation, an Innovative Loading Regime for Cartilage Tissue Engineering

Evaluation of Sliding Indentation, an innovative Loading Regime for Cartilage Tissue Engineering

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INTRODUCTION

Insufficient load-bearing capacity of today's tissue-engineered cartilage (TEC) is a limiting factor in bringing TEC to clinical application. While the crucial role of the collagen network in native cartilage is load-bearing, sufficient collagen content has not been generated in TEC. One reason is that the physical signals required to develop cartilage with a physiological amount of collagen are unknown. Recently, promising experimental results using an innovative loading regime based on sliding of compressing indenters presented by different groups [1-2]. During sliding indentation, a rigid cylinder indents a TEC construct and subsequently slides over it at a particular velocity. In this way, the tissue is locally stimulated, rather than globally such as with unconfined compression.

In this study, we question whether this loading regime induces strain fields in agarose-cell constructs that can potentially enhance the developing collagen structure. We approach this question by evaluating strain magnitudes and directions computed with a numerical model.

METHODS

Using the finite element method (Abaqus 6.7, Simulia, USA), the strain field in a 12 mm long and 2 mm high 2% (w/v) agarose-cell construct is computed, which is indented 5, 10 and 15% with a 4.5 mm diameter indenter, sliding at 0.2 mm/s. Contact between indenter and sample is assumed frictionless.

A validated nonlinear biphasic material model is used with compressible Neo-Hookean solid matrix behavior [3]

$$\boldsymbol{\sigma}_s = \frac{1}{2}K(J-\frac{1}{J})\mathbf{I}+\frac{G}{J}(\mathbf{B}-J^{2/3}\mathbf{I}) \quad (1)$$

where **B** is the Cauchy Green deformation tensor, **I** is the unit tensor and J is the volumetric deformation**.** K and G are the bulk and the shear modulus, respectively. Material parameters for agarose are fitted from experimental data (K=8.5 kPa, G=12.2 kPa) [4].

RESULTS

When the indenter moves over the construct, the strain field varies in time. Cyclic compression, shear, tension and fluid pressurization are imposed on the cells. Under the indenter, cells experience high tensile strain parallel to the surface (Fig 1). Adjacent to this area, the direction of the tensile principal strain changes gradually towards perpendicular in off-center areas (Fig 2). The maximum tensile strain in the tissue during a sliding cycle exceeds the imposed indentation strain, reaching 23%, 18% and 14% for 15%, 10% and 5% indentation depth, respectively. The induced strain is not equal throughout the depth of the tissue. The principal strains are large near the surface and strain magnitudes ameliorate in the deeper areas (Fig 3).

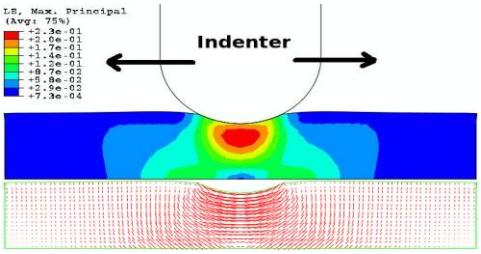

Figure 1. Distribution (top) and orientation (bottom) of the maximum principal strain at 15% compression.

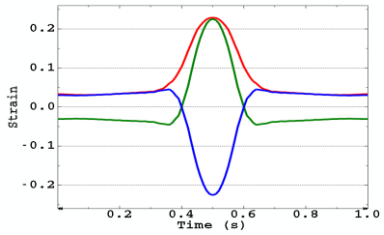

Figure 2. Cyclic maximum principal strain (red), horizontal strain (green), and vertical strain (blue) for 15% indentation, at a point located in the center of the high strained, red area in Fig 1.

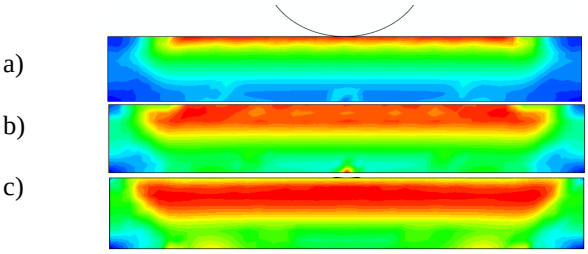

Figure 3. Distribution of the maximal principal strain during a full sliding cycle at a) 5%, b) 10% and c) 15% indentation.

DISCUSSION

The promising new concept of sliding indentation is evaluated. Cyclic compression, shear, tension and fluid pressurization are imposed in varying magnitudes and directions with sliding of the indenter. We postulate that this highly varying strain field may explain the enhanced collagen synthesis observed in the experiments [1-2].

The next step is to monitor cellular activities and matrix formation, and to compare these with the applied strain fields. This will elucidate the cellular response to the strains, which can be used to tune the strain field for optimal tissue formation. Applying such optimized loading regime is well possible with the sliding indentation approach, as illustrated by the large change in applied strain field in response to a modest change in the loading regime (Fig 3).

References

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